

**Research Title: Passivation of InAs and GaSb with novel high  $\kappa$  dielectrics**

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**InAs MOS devices with MBE-grown  $\text{Gd}_2\text{O}_3$  passivation**

InGaAs with high  $\kappa$  dielectrics is now viable for complementary metal-oxide-semiconductor (CMOS) devices beyond the 15 nm node technology. Recently, intensive research activities for achieving low interface density of states and excellent performance of inversion-channel MOS field-effect transistors<sup>[1-4]</sup> have been put on  $\text{In}_x\text{Ga}_{1-x}\text{As}$  ( $x=0, 0.2, 0.53, 0.75$ ), however, with less efforts on InAs.<sup>[5]</sup> Note that the latter has very high bulk electron mobility ( $\sim 30000 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ ) and saturation velocity ( $\sim 8 \times 10^7 \text{ cm/s}$ ). In this work, chemical and electronic characteristics on  $\text{Al}_2\text{O}_3/\text{Gd}_2\text{O}_3/\text{InAs}$  interface were studied using x-ray photoelectron spectroscopy (XPS). Electrical properties for MOSCAPs and depletion-mode MOSFETs were also studied.

The samples were grown by solid-source molecular beam epitaxy (MBE) on semi-insulating (100) GaAs substrate. The structure, following the growth sequence, consisted of a 200 nm-thick GaAs buffer layer, a 10 nm-thick AlAs transition layer, a  $0.2 \mu\text{m}$  AlSb/  $1.3 \mu\text{m}$   $\text{Al}_{0.7}\text{Ga}_{0.3}\text{Sb}$  composite buffer layer, a 20 nm AlSb barrier, and a 5 nm-thick InAs channel layer. A tellurium  $\delta$ -doping was placed at 25 nm below the InAs channel layer. The sample was then passivated by

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arsenic at low temperature and ex-situ transferred for deposition of high  $\kappa$ 's. An additional InAs layer ( $\sim 2$  nm) was freshly grown before the subsequent  $\text{Gd}_2\text{O}_3$  (3 mono-layers) was e-beam evaporated to passivate the InAs surface; finally, followed by the atomic layer deposited  $\text{Al}_2\text{O}_3$ .

Energy-band offsets of the ALD- $\text{Al}_2\text{O}_3/\text{Gd}_2\text{O}_3/\text{InAs}$  were obtained using XPS. The valence-band offset  $\sim 3.92$  eV was determined by measuring the core level to valence band maximum binding energy difference from the XPS spectra, as shown in Fig. 1. With energy-band gaps of 0.35 and 6.7 eV for InAs and  $\text{Al}_2\text{O}_3$ , the important parameter for MOS devices, conduction-band offset  $\sim 2.43$  eV, were determined.<sup>[6]</sup> The sample was annealed in  $\text{N}_2$ -ambient at  $300^\circ\text{C}$  for 60 seconds before the process.

Gate-first process was used to fabricate the ring-gate device. Gate metal, Ti/Au, was first formed by a lift-off process. The ohmic metal was subsequently formed by gate oxide wet-etching, metal deposition and lift-off. The cross-section and top view of the device is shown in Fig. 2. MOS diodes fabricated via the same process exhibited C-V curves with minor dispersion, as shown in Fig. 3. A  $12\mu\text{m}$ -gate-length device demonstrates a saturation drain current ( $I_{\text{d-sat}}$ ) of  $45\mu\text{A}/\mu\text{m}$  (at  $V_{\text{g}}=2\text{V}$  and  $V_{\text{d}}=2\text{V}$ ), and a transconductance of  $18\mu\text{S}/\mu\text{m}$  (at  $V_{\text{d}}=2\text{V}$ ).

## References

- [1] T. D. Lin *et al.*, APL **93**, 033516 (2008)
- [2] Y. Xuan *et al.*, IEEE Electron Device Lett. **29**, 294 (2008)
- [3] D. Lin *et al.*, Tech. Dig. – IEDM **2009**, 327
- [4] C. A. Lin *et al.*, APL **98**, 062108 (2011)
- [5] N. Li *et al.*, APL **92**, 143507 (2008)
- [6] M. L. Huang *et al.*, APL **94**, 052106 (2009)

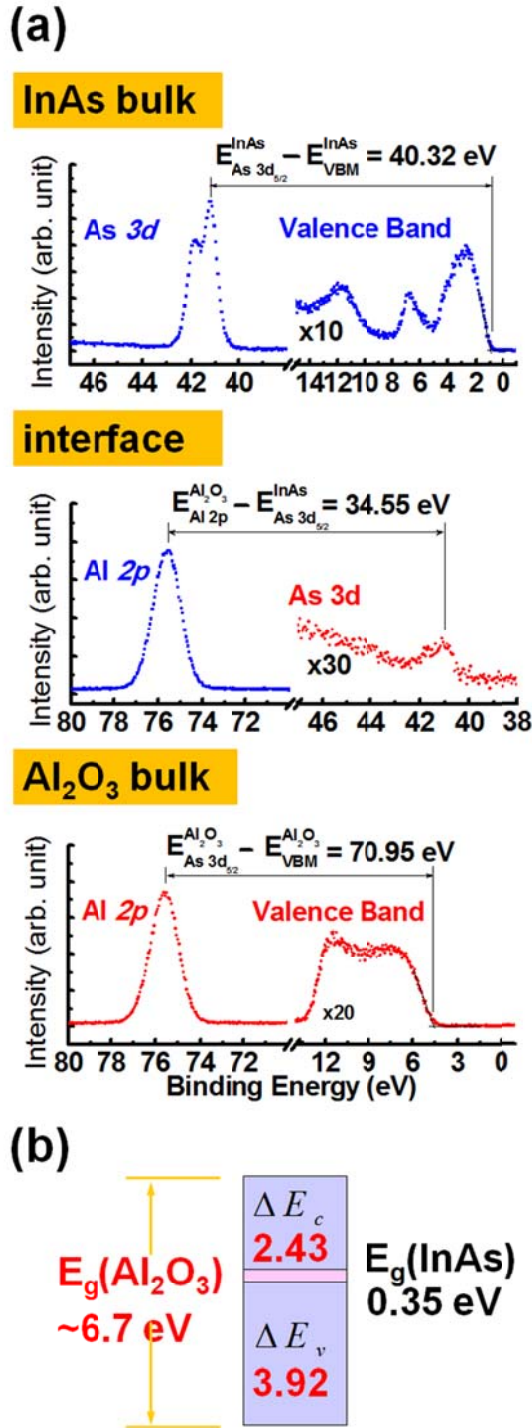


Fig. 1 (a) XPS spectra of As 3d CL and valence band of InAs film, Al 2p and As 3d CLs at ALD-Al<sub>2</sub>O<sub>3</sub>/Gd<sub>2</sub>O<sub>3</sub>/InAs interface, and Al 2p CL and valence band of Al<sub>2</sub>O<sub>3</sub> film. (b) Energy-band parameters

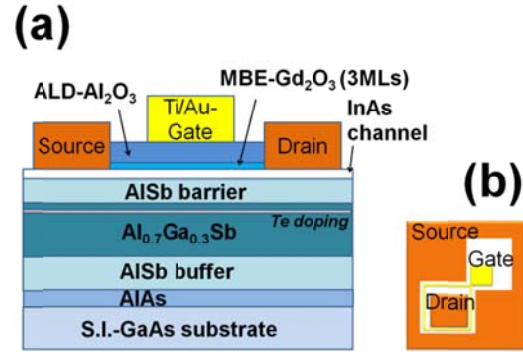


Fig. 2 (a) Cross-section and (b) schematic top-view of D-mode Al<sub>2</sub>O<sub>3</sub>/MBE-Gd<sub>2</sub>O<sub>3</sub> (3MLs)/InAs MOSFET.

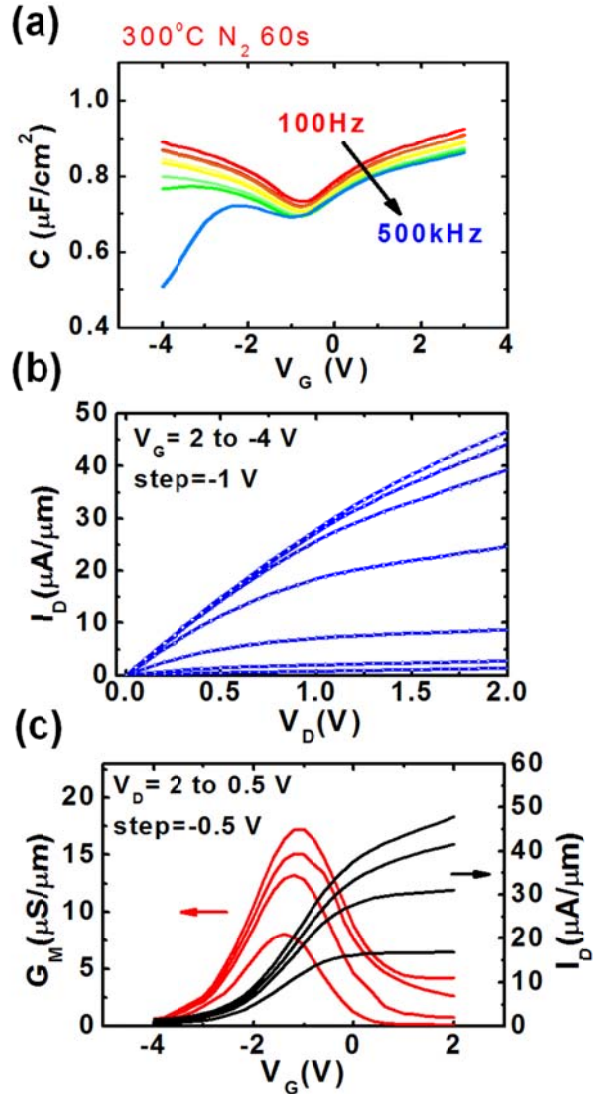


Fig. 3 (a) CV curve (b) Output characteristics  $I_D$  vs  $V_D$  and (c) transfer characteristics of depletion-mode *i*-InAs MOSFET with 12μm gate length.